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# Deformation of the Rock Mass in the Drift Scale Test

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## Introduction

The United States Department of Energy (DOE) is investigating Yucca Mountain, Nevada, for its feasibility as a potential deep geological repository of high-level nuclear waste. In a deep geological repository, radioactive decay heat released from high-level nuclear waste will heat up the rock mass. Although the following discussion about the thermal-hydrological (TH) process may not be directly relate to the topic of this paper, it provides a bigger picture of the processes in a potential repository. The heat will mobilize pore water in the rock mass by evaporation, or boiling if the thermal load is great enough. The water vapor/steam will flow away from the heat source because of pressure and thermal gradients and the effects of buoyancy force. The vapor/steam will flow along fractures or highly permeable zones and condense into liquid water in the cooler regions. Gravity and the fracture network will control the drainage of the condensed water. Some water may flow back toward the waste package and re-evaporate. This TH process will affect the amount of water that may come into contact with the waste package. Water is the main concern in maintaining the integrity of the waste package and the waste form, and the potential transport of radioactive nuclides. Thermally driven chemical and mechanical processes may affect the TH process. The heat will deform the rock mass by expanding the minerals in it. Within the matrix, the thermal expansion of minerals may create grain-boundary cracks, due to uneven thermal expansion coefficients of various minerals. On a larger scale, matrix thermal expansion may cause complicated deformations in the fractures. Fracture deformation includes normal deformation that may open or close fractures, and shear slips along fractures. The coupled thermal-hydrological-mechanical-chemical (THMC) processes need to be understood before repository performance can be adequately predicted. DOE is conducting field thermal tests to provide data for validating the model of the coupled THMC processes. Therefore, understanding the processes revealed by a field thermal test is essential for the model validation. This paper presents some preliminary investigations of the deformation of the rock mass as measured by multiple point borehole extensometers (MPBX) in the Drift Scale Test (DST), as it relates to the thermal-mechanical (TM) portion of the coupled THMC processes.

**Drift Scale Test**

So far, the DST is the biggest in situ thermal test conducted by DOE Yucca Mountain Project. The DST layout and design can be found in Sections 3 and 4 of Drift Scale Test As-Built Report [1] . The DST facility consists of a Heater Drift (HD), an Access-Observation Drift (AOD), and a Connecting Drift (CD). The HD is about 5.5 m in diameter, and about 47 m long. The heat source includes nine waste package-size electrical heaters on the floor of the HD and 50 wing heaters in boreholes on both sides of the HD (25 wing heaters on each side). A thermal bulkhead is placed near the junction of the HD and the CD. The xyz coordinates of the DST originate at the HD–side of the bulkhead. The total heating power from the nine floor-heaters and the wing heaters are about 68 kW and 143 kW respectively.

Each wing heater is divided into two sections. The power output for the inner section and the outer section are 1.145 kW and 1.719 kW respectively. The greater heat output from the outer section is to balance the edge cooling effect. The DST heaters were energized on 12/3/97. The test is planned to heat for four years, followed by a natural four year cool-down. Recently, heater power has been reduced in order to keep the drift wall temperature at about 200°C. Currently, heater power is at about 90% of its original level.

The DST monitors the coupled THMC processes using a broad range of instruments. Instruments installed in the DST measure the spatial distribution and temporal variation of temperature, moisture content, deformation, air permeability, gas pressure, relative humidity, gas chemistry, water chemistry, heater power, and other miscellaneous measurements. The TM responses are monitored by MPBX. The MPBX holes in the heated block of the DST are listed in Table 4-1 and illustrated in Figure 4-3 of Drift Scale Test As-Built Report [1] . The MPBX holes include hole #42-44, #81-82, #147-150, #154-157, and #178-181. In each of those MPBX holes several Geokon C-ring anchors are installed at various locations. Each of the anchors is connected to a Delrin MPBX head at the collar with an Invar rod. There are 6 anchors in each of holes #42-44 and #81-82; there are 4 anchors in each of the rest of the MPBX holes listed above. A linear variable displacement transducer (LVDT) measures displacement of each anchor with respect to the MPBX head at the collar. Temperatures in the MPBX holes are measured by thermocouples installed adjacent to the Invar rods. The average temperature in a hole is used to correct for the thermal expansion of the Invar rods. Only the displacement data in holes #81 and #82 are used in this paper because these two holes cover almost the entire length of the HD (see below), and because the displacement data in these two holes do not have the noise, apparently associated with temperature variations, other holes have. Holes #81 and #82 are two horizontal holes parallel to the axis of the HD, at about 3.7 m above the wing heater plane, and a horizontal distance of about 7 m from the centerline of the HD. When looking at the bulkhead from outside the HD, #81 is on the right-hand side, and #82 is on the left-hand side (between the AOD and the HD). Both 81 and 82 are about 46 m long, and they cover about 35 m of the 47 m long HD.

**Results and Discussion**

Figure 1 shows the displacement history of the 6 anchors in hole #81. The displacement data have been corrected for the thermal expansion of the Invar rods. The displacements are measured with respect to a reference point at the collar of the hole, which is about 11.13 m outside (on the cold side) of the bulkhead. The distance between anchors 1 to 6 and the collar are 7.5, 15.0, 25.0, 27.0, 39.0, and 45.0 m respectively. Both anchors 1 and 2 show movement towards the collar, while the other 4 anchors move away from the collar. These displacement data are in agreement with the concept that, on a macroscopic scale, heat expands the rock mass. The variations in the displacement curves, such as that on day 100 for anchor 6, and those on day 200 and 230 for most anchors, are probably due to discrete movements at those anchors. Similar displacement data are seen in hole #82, except that the displacements are more uniform, because of uniform anchor spacing of about 7 m, as shown in Figure 2. In hole#82, anchors 1 to 6 are at 11.2, 18.2, 25.2, 32.2, 39.2, and 45.5 m from the collar respectively. The collar is about 10.96 m outside of the bulkhead.

Figure 3 shows strain history between anchors in hole #81. The strain is calculated by dividing the differential displacements between anchors by the distance between the anchors. Also included at the bottom of this figure is the fracture information in this hole, as observed by video logs. The compressive strain and the small expansive strain at anchors 1 and 2 are due to the fact that these two anchors are in the cooler region. The fracture intensity is about the same for regions between all anchors, except between anchors 3 and 4. There are only a couple minor fractures between 3 and 4. This is reflected by the great expansive strain between 3 and 4. A major portion of the matrix expansive strain in other regions is absorbed by the fractures. Some fracture closures and/or slips along fractures are expected in regions between 2 and 3, 4 and 5, and 5 and 6.

In summary, the mechanical displacement data obtained by MPBX in the DST verify that heat expands rock mass. Thermal expansive strain is the greatest for regions without too much fracturing and deformation in fractures reduces the expansive strain. These data and the data from other MPBX holes are being analyzed in greater details in order to identify the coupling between the TM and TH processes. This analysis includes discrete element modeling of the THM process [2] .

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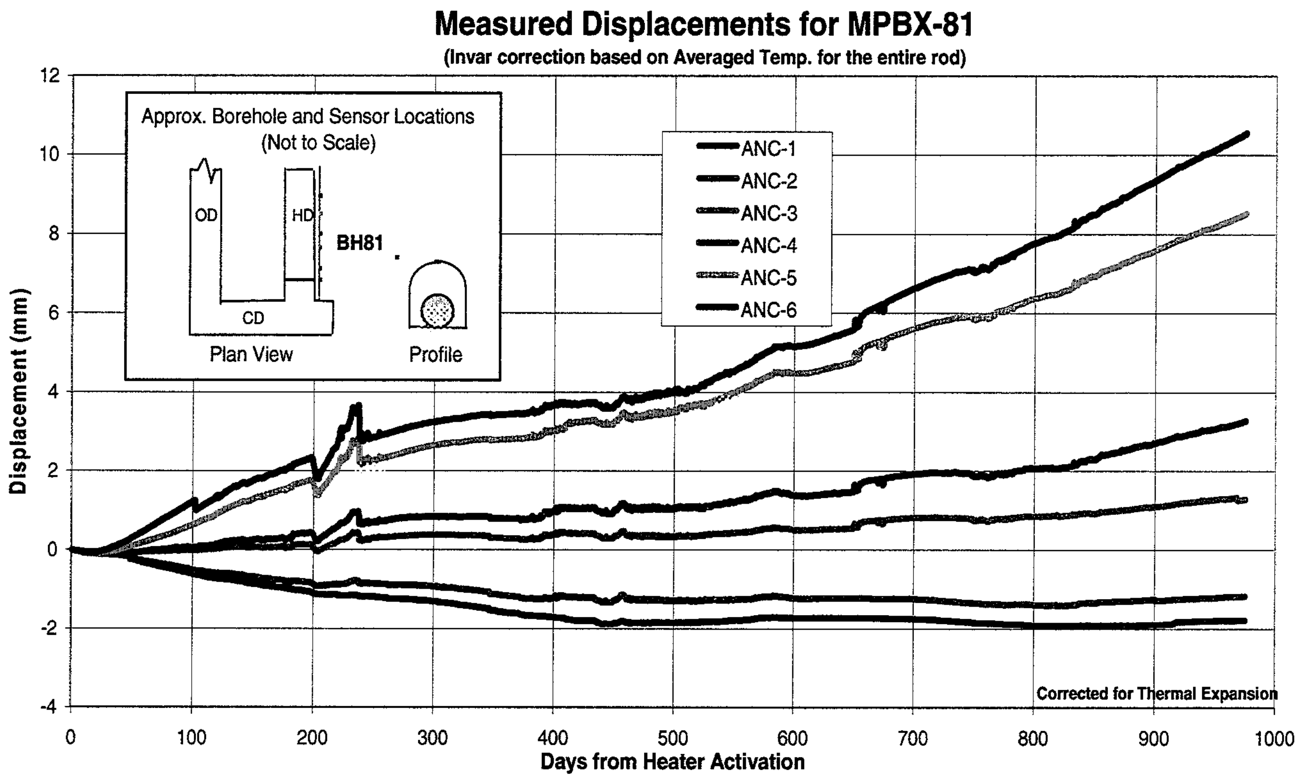



Figure 1. Displacement at anchors in hole#81 of the DST as a function of elapsed time. The displacement data have been corrected for the thermal expansion of the Invar rods. The insert shows the approximate location of the hole in the DST facility.

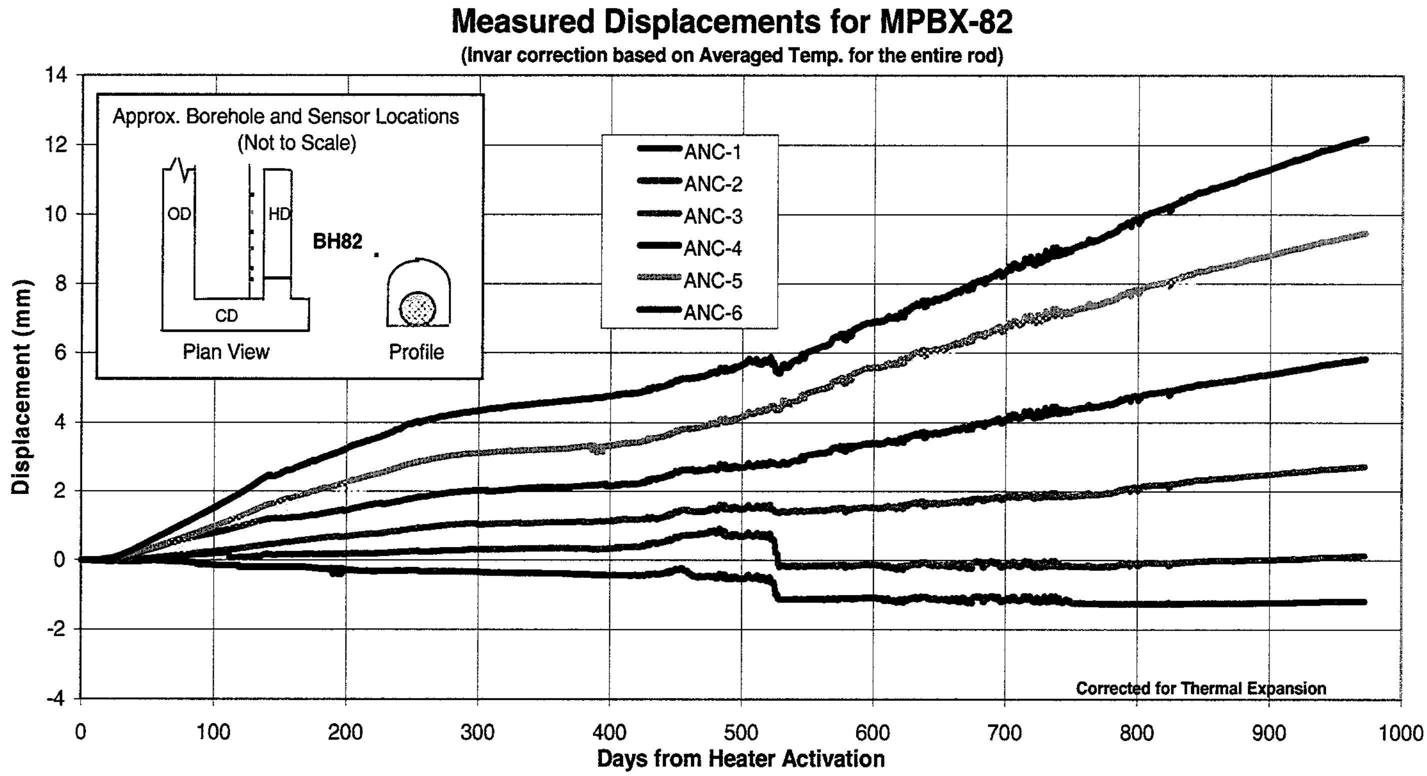
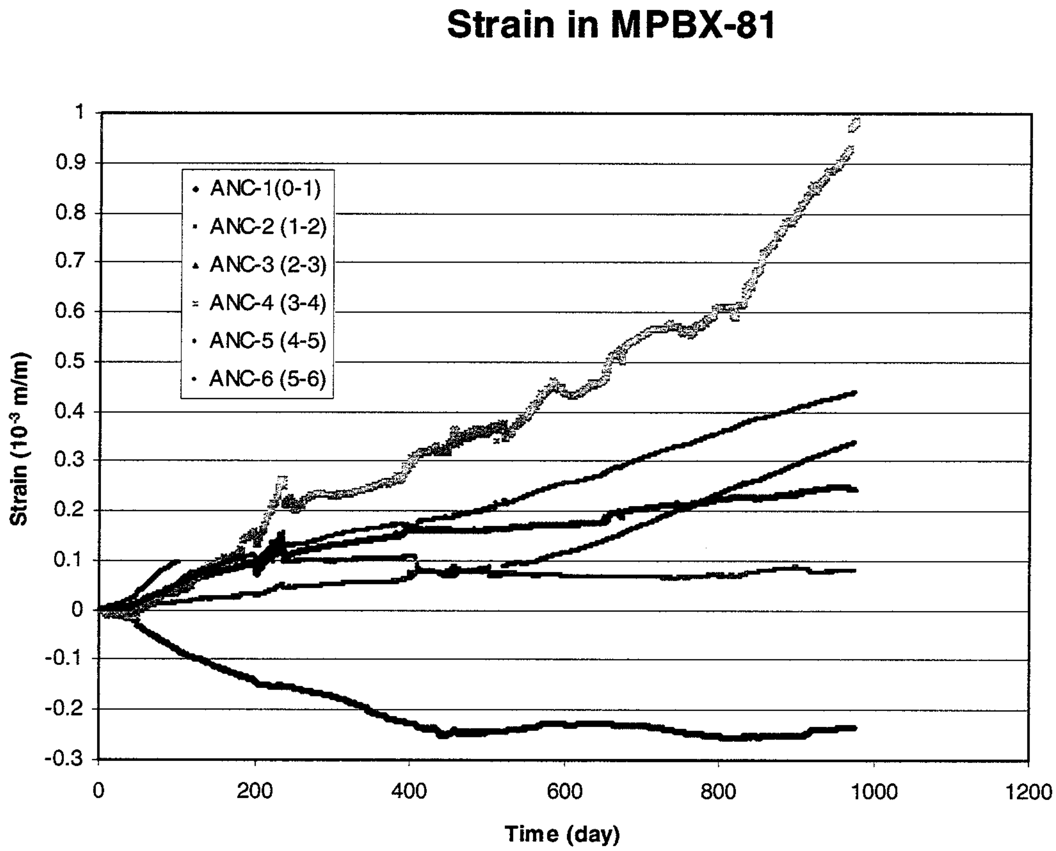



Figure 2. Displacement at anchors in hole#82 of the DST as a function of elapsed time. The displacement data have been corrected for the thermal expansion of the Invar rods. The insert shows the approximate location of the hole in the DST facility.

## Strain in MPBX-81



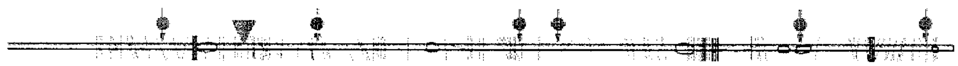



Figure 3. (Top) Strain between anchors in hole#81 of the DST, as a function of time. For example, ANC-2 (1-2) is the strain between anchors 1 and 2. (Above) Fractures in hole#81. The collar is at the left-end of the bar. The blue dots are anchors, from left to right, 1 to 6. The green triangle represents the bulkhead. The bulkhead is 11.13 m from the collar. Heavy red lines are major fracture zones; light red lines are major discrete fractures; red circles are low angle major fractures; gray lines are minor to moderate fractures.